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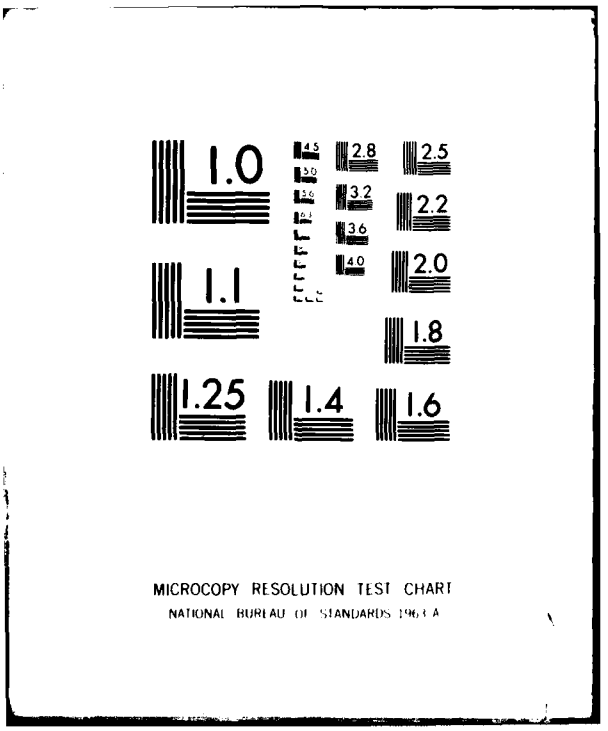
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Spacecraft Charging on ATS-5

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The distribution of plasma electron and proton temperature at the time of spacecraft charging events during eclipse are obtained from ATS-5 data for 1969 to 1971. The mean RMS electron temperature is 3 keV and the highest value measure is 6.5 keV. The mean RMS ion temperature is 9 keV; the highest value is 12 keV. The current-voltage characteristic curve shows that a threshold current for charging exists which is ~~1 × 10⁻⁸ A/m²~~. The charging current has a narrow distribution around ~~1.5 × 10⁻⁶ A/m²~~. The spacecraft ground potential varies approximately linearly with RMS plasma electron

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temperature consistent with the behavior of a dielectric probe in a plasma.

Contents

1.	INTRODUCTION	5
2.	PLASMA CHARACTERISTICS	6
3.	TEMPERATURE DISTRIBUTIONS	6
4.	ECLIPSE CHARGING VOLTAGES	7
5.	CHARGING CURRENT	8
6.	I-V CHARACTERISTIC	8
7.	ECLIPSE VOLTAGE VERSUS ELECTRON TEMPERATURE	9
8.	DISCUSSION OF ATS-5 RESULTS	9
9.	WORST CASE PARAMETERS	9
10.	CHARGING PREDICTION	10
REFERENCES		11

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Illustrations

1. Distribution of RMS Electron Temperatures at Geosynchronous Orbit Measured on ATS-5, 1969 to 1971 7
2. Distribution of RMS Ion Temperatures at Geosynchronous Orbit Measured on ATS-5, 1969 to 1971 7
3. Distribution of 10-min Averages of Spacecraft Ground Potentials During Eclipse for ATS-5 7
4. Distribution of Peak Spacecraft Ground Potentials During Eclipse for ATS-5 7
5. Distribution of Eclipse Charging Currents for ATS-5 8
6. Current-Voltage Characteristic Curve for ATS-5 8
7. Dependence of ATS-5 Ground Potential on RMS Plasma Electron Temperature 9

Spacecraft Charging on ATS-5

1. INTRODUCTION

Spacecraft in geosynchronous orbit are subject to electrostatic charging to more than 10 kV by substorm plasmas.[1] Such high potentials can cause arcing in spacecraft surface materials, and can lead to spacecraft damage. Since its discovery, spacecraft charging has been explained by a model in which the spacecraft is viewed as a probe in a plasma.

This study of the statistical properties of the plasma at geosynchronous orbit is designed to show how well the probe model fits the observations of the charging potentials of the ATS-5 spacecraft.

Knowledge of plasma conditions at geosynchronous orbit is at present derived from the ATS-5 and ATS-6 satellite measurements.[2,3] The former has also provided information about potentials during charging events and their correlation

(Received for publication 9 May 1980).

1. DeForest, S. E. (1972) Spacecraft charging at synchronous orbit, J. Geophys. Res. 77:651.

2. Garrett, H. B. (1979) Review of quantitative models of the 0- and 100-keV near-earth plasma, Res. Geophys. and Space Phys. 17:397.

3. Johnson, B., Quinn, J., and DeForest, S. (1978) Spacecraft charging on ATS-6, Effect of the Ionosphere on Space and Terrestrial Systems, John M. Goodman, Ed., U.S. Government Printing Office, Washington, D.C.

with plasma conditions;[4] ATS-5 has accumulated data on spacecraft charging during eclipse for three years, 1969 to 1971, which comprises 108 charging events. This entire data base will be utilized here, in order to obtain improved statistics on charging potentials and electron and proton temperatures.

Root-mean-square electron and proton temperature distributions during eclipse charging events are obtained, as well as the distribution of spacecraft ground potentials. Further, the distribution of currents to the spacecraft during charging events is determined. Spacecraft ground potential versus ambient current shows a threshold current for charging. Finally, a plot of spacecraft ground potentials versus RMS electron temperature shows a threshold behavior, as well as an approximately linear relationship of potential to electron temperature above threshold, consistent with probe charging theory.

2. PLASMA CHARACTERISTICS

The data employed was measured on the ATS-5 satellite from 1969 to 1971. This satellite was in geosynchronous orbit near 105°W longitude with an orbital inclination of 2.30° and spinning with an axis parallel to the earth's rotational axis with a period of 0.79 sec. Electrostatic analyzers of the University of California at San Diego plasma experiment provided the data for the determinations of spacecraft potentials and plasma temperatures.

The RMS electron temperature employed here is defined as the energy flux divided by twice the number flux. Although the plasmas at geosynchronous orbit are not usually Maxwellian, an approximate Maxwellian fit to the distribution function will enable us to obtain an estimate of the temperature distributions. In this way, the electron and proton distributions can be compared.

3. TEMPERATURE DISTRIBUTIONS

The RMS temperature distributions of protons and electrons were obtained just before the spacecraft entered eclipse and just after exit from eclipse. During eclipse, the spacecraft charges up and distorts the measured energy spectra so that pre-eclipse and post-eclipse spectra were thought to be more accurate representations of the plasma.

Figures 1 and 2 show the distribution of RMS electron and proton temperatures, respectively. The electron temperature distribution is peaked close to 3 keV and the ion distribution close to 9 keV. For the 1969 to 1971 time period, electron temperature of greater than ~7 keV was rare.

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4. Garrett, H. B., and Rubin, A. G. (1978) Spacecraft charging at geosynchronous orbit: generalized solution for eclipse passage, Geophys. Res. Lett. 5:865.

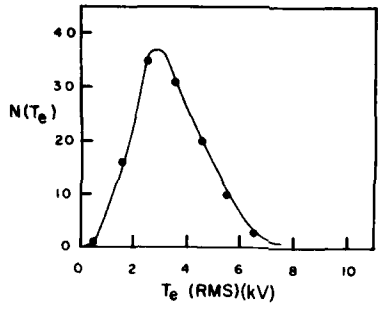

Figure 1. Distribution of RMS Electron Temperatures at Geosynchronous Orbit Measured on ATS-5, 1969 to 1971

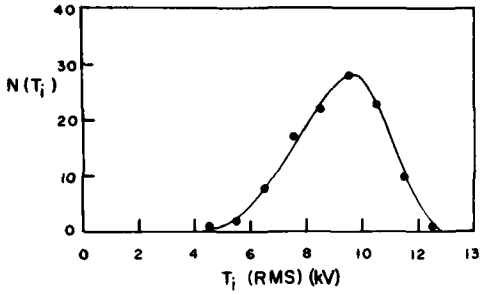

Figure 2. Distribution of RMS Ion Temperatures at Geosynchronous Orbit Measured on ATS-5, 1969 to 1971

4. ECLIPSE CHARGING VOLTAGES

Figure 3 shows the distribution of 10-min averages of the eclipse charging voltage. The charging voltage shown here is obtained from the shift of the proton spectrum when the spacecraft is charged; it represents the spacecraft ground potential. The voltage distribution is a declining function of voltage with an end point of the distribution of 10-min averages at about 8 kV.

Figure 4, the distribution of peak voltages, shows a distribution end point of about 10 kV.

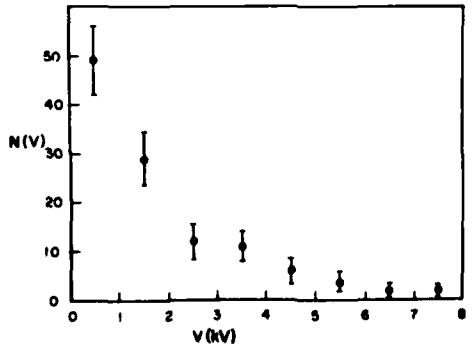

Figure 3. Distribution of 10-min Averages of Spacecraft Ground Potentials During Eclipse for ATS-5

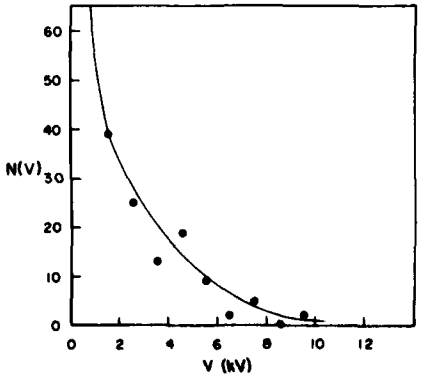

Figure 4. Distribution of Peak Spacecraft Ground Potentials During Eclipse for ATS-5

5. CHARGING CURRENT

Figure 5 shows the distribution of charging currents. It is noteworthy that the distribution is very narrow with most of the charging taking place for currents in the range of 1 to 3 $\mu A/m^2$. The current distribution is peaked at $\sim 1.5 \times 10^{-6}$ A/m^2 so that this is a useful quantity to remember for charging calculations.

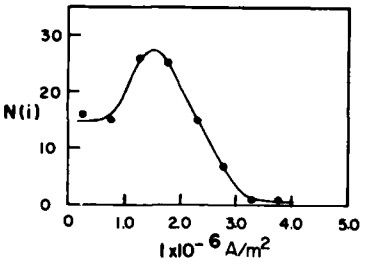

Figure 5. Distribution of Eclipse Charging Currents for ATS-5

6. I-V CHARACTERISTIC

One may plot the observed voltage as a function of charging current as shown in Figure 6. Because of the large dispersion in this curve, it is of limited use. However, it does show that there is a threshold current for charging of 1×10^{-6} A/m^2 below which charging is not observed.

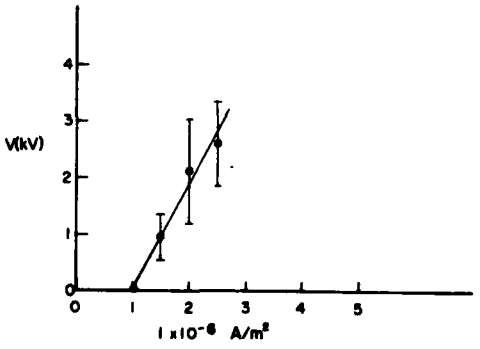

Figure 6. Current-Voltage Characteristic Curve for ATS-5

7. ECLIPSE VOLTAGE VERSUS ELECTRON TEMPERATURE

Figure 7 shows ATS-5 ground potentials plotted versus RMS electron temperatures. For electron temperatures below ~1.5 keV, there is no charging. Above this threshold value, the spacecraft potential varies almost linearly with electron temperature.

The linear dependence of spacecraft potential on plasma electron temperature above a threshold is typical of a dielectric probe in a plasma for which secondary electron emission is taken into account. The secondary electron yield curve is a decreasing function of energy and crosses unity at some upper crossover energy. If there is a net electron flux at energies greater than the upper crossover energy, then the probe will charge negatively. The upper crossover of the secondary electron yield curve can account for the threshold in charging potential versus electron temperature curves similar to Figure 7. Since the ATS-5 surface is composed of a variety of dielectrics and conductors, the charging curve for any single material would not fit the data precisely.

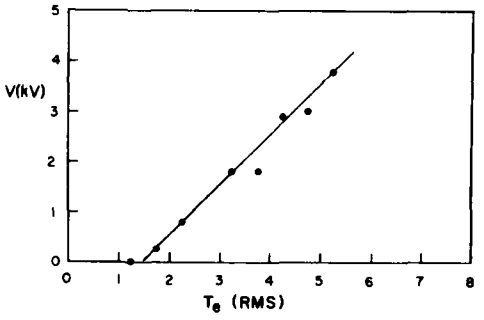

Figure 7. Dependence of ATS-5 Ground Potential on RMS Plasma Electron Temperature

8. DISCUSSION OF ATS-5 RESULTS

For the purpose of protecting against spacecraft charging and for designing spacecraft with charging in mind, it is necessary to know the parameters of the ambient plasmas as well as the range of voltages encountered.

9. WORST CASE PARAMETERS

For the 1969 to 1972 period, the highest electron temperature was less than 7 keV and the highest potential less than 10 kV.

For charging currents, the average value is 1.5×10^{-6} A/m^2 and the highest value $\sim 4 \times 10^{6}$ A/m^2. There is a threshold current for charging, 1×10^{-6} A/m^2.

10. CHARGING PREDICTION

The form of the potential versus electron temperature curve, or alternatively, the theory of charging of dielectric probes in a plasma may be used to predict charging in the environment at geosynchronous orbit. Discharges caused by charging give rise to spacecraft problems, as distinct from the mere presence of voltage differentials on spacecraft surfaces. At present, mechanisms of surface discharges on spacecraft are not well established.[5,6] The distribution of potentials encountered on ATS-5 provides information enabling one to distinguish between proposed discharge models. The measured potentials are rather low to account for discharges through the bulk of dielectric materials such as Kapton, based on measured breakdown potentials in the laboratory, implying that some more complicated mechanism may, in fact, be operative.

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5. Hazelton, R.C., Churchill, R.J., and Yadlowsky, E.J. (1979) Measurements of particle emission from discharge sites in teflon irradiated by high energy electron beams, IEEE Trans. Nucl. Sci. NS-26:5141-5145.

6. Flanagan, T.M., Denson, R., Mallon, C.E., Treadway, M.J., and Wenaas, E.P. (1979) Effect of laboratory simulation parameters on spacecraft dielectric discharges, IEEE Trans. Nucl. Sci. NS-26:5134-5140

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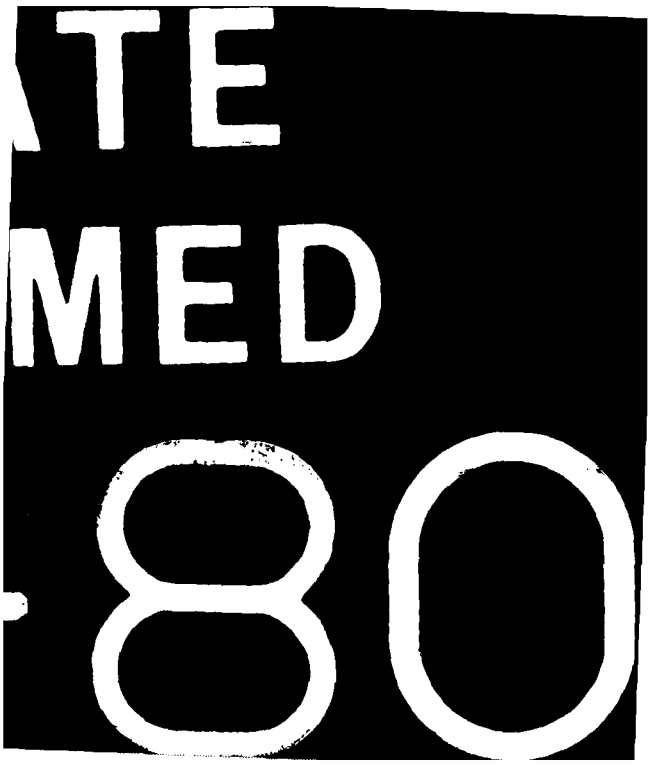
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